

Consistency in On-Road Mobile Source Activity Modeling, with an Application to Parked Passenger Cars

Harvey Michaels and David Brzezinski
U.S. EPA Office of Transportation and Air Quality
2000 Traverwood Drive, Ann Arbor, MI 48103
michaels.harvey@epa.gov, brzezinski.david@epa.gov

Sue Kimbrough
U.S. EPA Office of Research and Development
MD E305-02
Research Triangle Park, NC 27711
kimbrough.sue@epa.gov

ABSTRACT

This paper motivates and describes an internally consistent approach to modeling on-road mobile source activity and applies it to emissions from parked passenger cars at the county level. Historically, on-road mobile source activity measurements and modeling have grown from highway engineering concerns, focusing on roadway travel and its associated issues of congestion and travel time. Hence, the basic unit of activity has been vehicle miles traveled (VMT). As emissions have gained in importance in public policy, these same travel measurements and models have been employed to calculate emissions, typically expressing non-traveling activity such as parked vehicles and extended idling in terms of VMT. However, once the ratio of non-traveling activities to VMT shifts, as it inevitably does over time or in policy analyses, inconsistencies develop. For example, diurnal emissions in a constant vehicle population, if treated as proportional to VMT (as they are, for example, in MOBILE), will increase with VMT, even though they should decrease, since more VMT in a fixed population implies less time parked. We present analyses demonstrating the importance of non-VMT related emissions from parked vehicles and from extended truck idling. We discuss the inter-relationships between activity parameters that govern the internal consistency of on-road mobile source activity modeling. We apply these ideas in detail to a county-level calculation of the population of parked passenger cars and show how our methods can be extended to national inventories.

1. INTRODUCTION

Historically, on-road mobile source activity measurements and modeling have grown from highway engineering concerns, focusing on roadway travel and its associated issues of congestion and travel time. Hence, the basic unit of activity has been vehicle miles traveled (VMT). As emissions have gained in importance in public policy, these same travel measurements and models have been employed to calculate emissions, typically expressing non-traveling activity such as parked vehicles and extended idling in terms of VMT. However, once the ratio of non-traveling activities to VMT shifts, as it inevitably does over time or in policy analyses, inconsistencies develop. For example, in a constant vehicle population, if diurnal emissions are treated as proportional to VMT (as they are, for example, in MOBILE), they will increase with VMT, even though they should decrease, since more VMT in a fixed population implies less time parked. Similarly, if a county decreases total VMT (such as by car pooling), then MOBILE predicts a decrease in all emission types, when, in fact, diurnal emissions will increase.

In order to model mobile source emissions in an environment of changing driving patterns, activity cannot simply be modeled as a function of VMT based on static relationships of mileage accumulation rate (MAR), daily trips, speed and commute patterns. As these and other variables are manipulated to reflect specific current driving regimes and to model future regimes and policy initiatives, it is necessary that the relationships between these variables remain consistent. For example, if VMT is assumed to change, we must determine the correct and consistent combination of changes in vehicle population and trip parameters. Non-traveling emissions need to be de-linked from VMT.

MOVES is a new model that EPA is developing to produce emission inventories for both on-road and non-road vehicles. As we have worked to integrate on-road and non-road emissions estimation into a single framework and to produce not just on-road emission factors but also on-road inventories, we have been forced to consider issues of internal consistency. Consistency requires integrating operating, parking, and idling into a single activity framework for both on-road and non-road vehicles. This framework should not hide the relationships between different parameters, but make them transparent and rational.

Internally, MOVES does not track activity with VMT, but rather with six *total activity bases*, listed in Table 1, that are more general and more directly related to specific emissions processes.

Table 1. Total activity bases proposed for MOVES.

<i>Total Activity Basis</i>	<i>Corresponding Emission Factor Units</i>	<i>Total Emissions Calculated</i>
Source Hours Operating (SHO)	grams/hour	Operating emissions
Source Hours Parked (SHP)	grams/hour	Parked (engine off) emissions
Source Hours (SH)	grams/hour	Continuous emissions independent of on/off status (e.g. outgassing)
Source Hours Extended Idling (SHEI)	grams/hour	Extended idling emissions
Starts (Starts)	grams/start	Start emissions
Gallons Refuelled (GR)	grams/gallon	Refuelling emissions

MOVES refers to mobile emissions producers as *sources*, rather than vehicles, because its design will apply to non-road equipment as well as on-road vehicles. Although VMT is not an internal activity basis for MOVES, it is easily converted to source hours operating (SHO) by dividing by average speed. The emission factors that would be multiplied by the total activity bases to produce emissions depend on the characteristics of the source (e.g., model year, age, technology, fuel), how it is being operated (e.g., speed, acceleration, power consumption), parked, idled, started, or refueled, and environmental parameters (e.g., temperature, humidity). More information on MOVES is available in the MOVES design plan¹ and the MOVES emissions analysis plan.²

In the next section, we discuss the magnitude of non-traveling emissions, to explain why we are concerned with parking and idling. In Section 3, we define some activity parameters, and in Section 4, we describe some important relationships between them that define consistency. In Section 5, we present a method for estimating parked populations from total and operating vehicle populations. In Section 6, we present an example of this method applied to passenger cars in a single U.S. county, but applicable nationally. Our summary and conclusions are in Section 7.

2. THE SIGNIFICANCE OF NON-TRAVELING EMISSIONS FROM ON-ROAD VEHICLES

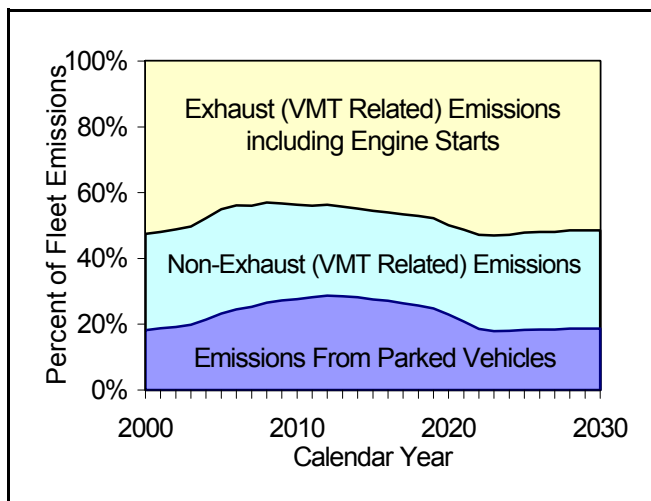
Why should we care about non-traveling emissions? The importance of on-road vehicle travel to emissions is obvious, and the most conspicuous measure of this activity is VMT. However, not all emissions from vehicles occur when they are traveling. Vehicles emit significant hydrocarbons (HC) when the engine is off, mainly due to the evaporation of fuel. In addition, significant emissions occur during extended idling, especially by long-haul trucks to power accessories when parked, but also by passenger cars in very cold or hot weather to maintain or bring interior temperatures to comfortable levels.

Importance of Evaporative Emissions

Hydrocarbons are emitted from vehicles by the following processes:

- Exhaust - Unburned fuel exhausted from the tailpipe.
- Running Losses - Vapors escaping from the fuel system driven by heating of the fuel during engine operation.
- Crankcase Losses - Vapors escaping from the crankcase caused by exhaust gases escaping through the piston rings (blow-by).
- Hot Soak Losses - Vapors (primarily unburned fuel in the intake manifold) that come off the hot engine after the engine is turned off.
- Diurnal Losses - Vapors escaping from the fuel tank while a vehicle is parked when the ambient temperature is rising.
- Resting Losses - Vapors permeating through fuel hoses and gaskets at all times.
- Refueling Losses - Vapors in the fuel tank displaced when the vehicle is refueled.
- Gross Liquid Leaks - Any significant loss of liquid fuel due to leaks in the fuel system.

Figure 1. Exhaust, non-exhaust, and parked emissions as a percent of annual on-road fleet HC emissions for Miami, Florida, from 2000 to 2030, based on MOBILE6 runs.



The changes over time are due to changes in fleet composition and regulation.

All of these processes are addressed in EPA's current emission factor model (MOBILE6),³ including the effects of ambient conditions and control strategies. Based on runs of MOBILE6, we have determined that in Chicago, the annual HC emissions from parked vehicles vary from 10 percent to 20 percent of the total annual emissions of the on-road fleet, while in Miami, with warmer temperatures, the parked vehicles account for 20 percent to 30 percent. Figure 1 shows the contribution from exhaust, non-exhaust, and parked emissions in Miami from 2000 to 2030. Exhaust emissions include those from both vehicle operation and engine starts. Non-exhaust (VMT-related) emissions include evaporative running losses, refueling losses and crankcase losses. Parked vehicle emissions include diurnal losses, resting losses and hot soaks. Fleet emissions include both gasoline and diesel fueled vehicles.

Standard practice has been to model hot soak losses, diurnal losses, resting losses, and leaks as proportional to VMT. However, they bear a more direct relationship to SHP, since they occur when vehicles are parked. In Sections 5 and 6 below, we describe a method for estimating SHP, which MOVES will use as the total activity basis for parked emissions.

Another source of emissions that is not directly accounted for by VMT is extended idling. Idling is defined as any time the engine is operating, but the vehicle velocity is zero. Idling occurs during normal driving, at traffic signals and during periods of extreme congestion. This type of idling is included as part of the driving cycles normally used to estimate emissions from vehicles. However, there are other types of idling that are not necessarily proportional to normal driving activity and should be considered separately from VMT based emissions.

Federal safety rules require that long-haul truck drivers spend no more than 10 hours driving before taking an 8 hour break. Many truck drivers sleep in their cabs during these breaks and run the truck engines to operate air conditioning and other accessories. On long cross-country trips, this behavior can cause engine idling to account for 40 percent of engine-on time. This behavior is not captured by direct measurements of VMT, since it is not a normal part of roadway activity. Estimates are that as many as 500,000 trucks are involved in this type of behavior during long-haul operations, and the resulting NOx emissions from long-term idling from these trucks may account for over 2 percent of NOx emissions from all on-road vehicles. Since emission standards are expected to have little effect on long-term idling emissions, the relative importance of long-term idling will grow dramatically in the future as the other sources of NOx emissions from these vehicles are controlled.

In addition, in cold-weather areas, light-duty vehicles are often idled for significant time periods to heat the engine and interior of the vehicle before driving. In extremely cold areas, vehicles may be idled for up to an hour before driving begins. Emission control devices (such as catalytic convertors) are often less effective during idling, so that long-term idling before a trip may have a disproportional impact on emissions. Strategies such as block heaters likely have small effects on the emission impact of this type of idling. Similarly, in warm weather areas and during summer months, vehicle owners often idle their vehicles with the air conditioning on to cool the interior of the vehicle before trips. This idling behavior may have disproportional impacts on emissions as well.

3. PARAMETERS USED TO CALCULATE ON-ROAD ACTIVITY

In addition to the total activity bases described above, other parameters come into play, either to calculate the activity bases, or to calculate the parameters on which emission factors depend. Activity parameters may be divided for convenience into four categories: vehicle populations, total activity bases, vehicle activity parameters, and trip parameters. These parameters are defined and given symbols below.

Vehicle Populations

In principle, populations are instantaneous (a snapshot), but as a practical matter they are averages over some time period. The shortest averaging period is generally an hour. But the number of vehicles in an area could also be averaged over 15 minutes, a day, or a year. Population values do not accumulate with time. The annual vehicle population in an area is the same as the average daily population averaged over the year. The units for vehicle populations are vehicles.

- Reg—The number of vehicles registered in a given area.

- Popn—The total number of vehicles in the area, which may be more or fewer than those registered.
- P—The number of vehicles parked in the area
- O—The number of vehicles operating in the area
- EI—The number of vehicles engaged in extended idling in the area

Total Activity Bases

Unlike population, these parameters accumulate over time. For example, the annual VMT is 365 times the average daily VMT. Activity measures are always associated with a time period over which they are summed. VMT or SHO could be for an hour, a day or a year. For clarity, these time references should be indicated explicitly by a prefix, for example, HVMT for hourly VMT. The prefixes are shown below for VMT. The other activity measures follow the same pattern, with “time” in the denominator of the units replaced by hour, day, month, or year.

- VMT—vehicle miles traveled. Units: vehicle · miles / time
- HVMT—hourly vehicle miles traveled. Units: vehicle · miles / hour.
- DVMT—daily vehicle miles traveled. Units: vehicle · miles / day.
- MVMT—monthly vehicle miles traveled. Units: vehicle · miles / month.
- AVMT—annual vehicle miles traveled. Units: vehicle · miles / year.

The following six parameters are the total activity bases for MOVES, which can, like VMT, be expressed per hour, day, month, or year:

- SHO—source hours operating. Units: source · hours / time.
- SHP—source hours parked (engine off). Units: source · hours / time.
- SHEI—source hours extended idling. Units: source · hours / time.
- GR—gallons refueled. Units: gallons / time.
- SH—source hours. Units: source · hours / time.
- Starts—number of starts. Units: starts / time.

Individual Vehicle Activity Parameters

- OnsPerDay—number of periods when the engine is on. Units: ons / day
 - OffsPerDay—number of periods when the engine is off. Units: offs / day
 - TripsPerDay—number of periods of travel. Units: trips / day
 - ExtendedIdlesPerDay. Units: extended idles / day
 - MAR—mileage accumulation rate. Units: miles / year
- MAR is obtained from survey data (such as the National Travel Household Survey⁴ and the Vehicle Inventory and Use Survey⁵), which distribute it by vehicle age.

Trip Parameters

A trip is the movement of a vehicle from one place to another.

- DistancePerTrip. Units: distance / trip
- TimePerTrip—time between trips. Units: time / trip
- TimePerOff. Units: time / off
- AverageSpeed. Units: distance / time

4. CONSISTENT RELATIONSHIPS BETWEEN ACTIVITY PARAMETERS FOR ON-ROAD MOBILE SOURCES

In order to model mobile source emissions in an environment of changing driving patterns, activity cannot simply be modeled as a static function of VMT. As variables are manipulated to model specific current driving regimes and to model future regimes and policy initiatives, the relationships between these variables must remain consistent. If VMT is assumed to change, we must determine the correct and consistent combination of changes in vehicle population and trip parameters. Non-traveling emissions need to be de-linked from VMT. These ideas need to be implemented for all scales of analysis, from the nation to an intersection.

Population and Total Activity Basis Relationships

Within an area, the population of vehicles must equal the sum of those operating on the roadways, those parked, and those engaged in extended idling:

$$\text{Popn} = \text{O} + \text{P} + \text{EI} \quad (1)$$

In terms of total activity bases, this equation can be written as

$$\text{SH} = \text{SHO} + \text{SHP} + \text{SHEI} \quad (2)$$

Substituting $\text{SHO} = \text{VMT}/\text{AverageSpeed}$, assuming $\text{SHEI}=0$ for passenger cars, and solving for VMT gives

$$\text{VMT} = \text{AverageSpeed} * (\text{SH} - \text{SHP}). \quad (3)$$

This equations indicates that if you measure an increase in VMT in a county, it must be accounted for by either an increase in average speed, and increase in the number of vehicles in the county, a decrease in the amount of time vehicles spend parked, or some combination of these. Since the measurement of VMT and vehicle populations are usually independent, making sure that the estimate of the time vehicles spend parked is consistent with the other measurements can be an important part of building an inventory. If all the terms in these equations are measured or estimated independently, an important consistency check is that they satisfy these equations.

For a closed domain (e.g. Hawaii) or one large-enough that cross-border traffic could be considered negligible (e.g., the continental United States), an important consistency check is that registrations equal population. We discuss below, in Sections 5 and 6, estimating county populations of passenger cars when there is asymmetrical inter-county travel, and, therefore, populations and registrations are not expected to be equal.

Relationships Involving Individual Vehicle Parameters

$$\text{OnsPerDay} = \text{OffsPerDay} = \text{StartsPerDay}, \quad (4)$$

where an “on” is some combination of trips and extended idling.

$$\text{AverageOnsPerDay} = \text{AverageOffsPerDay} = \text{AverageStartsPerDay}. \quad (5)$$

The distributions of ons, offs, and starts must be similarly related. For example, offs occur between ons, and starts occur at the ends of offs and the beginnings of ons.

MAR, which is derived from survey data, should be checked against VMT, which is derived from traffic volume measurements:

$$AVMT \approx MAR * Popn \quad (6)$$

Relationships Involving Trip Parameters

$$TripDistance / TripTime = AverageTripSpeed. \quad (7)$$

$$AverageTripDistance * AverageTripsPerDay * Popn = DVMT \quad (8)$$

$$OnsPerDay * AverageTimePerOn = 24 - OffsPerDay * AverageTimePerOff. \quad (9)$$

$$TripsPerDay * AverageTimePerTrip + ExtendedIdlesPerDay * AverageExtendedIdleTime + OffsPerDay * AverageTimePerOff = 24 \quad (10)$$

As an example of how groups of these parameter are related to each other, the above equations can be combined and rearranged to give *AverageTimePerOff* as a function of VMT, population, average speed, and *TripsPerDay*. In this equation, we have ignored extended idling, as would be appropriate for most of the passenger car fleet.

$$AverageTimePerOff = \frac{1}{TripsPerDay} \left(24 - \frac{DVMT}{Popn * AverageSpeed} \right) \quad (11)$$

To interpret this equation, observe that the fraction on the right is the operating time per vehicle per day, so the term in parentheses is the parked time per vehicle per day. Dividing the latter by the *TripsPerDay* gives the *AverageTimePerOff*. Varying only one parameter at a time: if *DVMT* or *TripsPerDay* increases, *AverageTimePerOff* decreases; if *AverageSpeed* or *Popn* increases, *AverageTimePerOff* increases. Of course, if two or more of these parameters are changed together, *AverageTimePerOff* may increase, decrease, or stay the same. In addition to these average relationships, changing the distribution of trips during the day will change the distribution of off times. The important point is that no parameter can be changed independently. If one parameter in these equations is changed, at least one other must also change. Distributions of the above parameters interact in the same tightly linked way that their averages do. For example, if trips are clustered, then most off times will be short and one or a few will be long. We need algorithms to model these interactions and to assure their consistency in inventory calculations.

5. ESTIMATING PARKED POPULATIONS FROM TOTAL AND OPERATING POPULATIONS

Rearranging Equation 1, the population of parked vehicles (P) equals the total population of vehicles (Popn) minus the population of operating vehicles (O) minus the population engaged in extended idling (EI):

$$P = Popn - O - EI. \quad (12)$$

For passenger cars in most counties, we can ignore extended idling, so

$$P = \text{Popn} - O. \quad (13)$$

The average population of operating passenger cars in a county during a given hour can be calculated from hourly VMT (HVMT) and average speed:

$$O = \text{HVMT} / \text{AverageSpeed}, \quad (14)$$

summed over different roadway types that have different average speeds. Then, to solve Equation 13 we need a method to estimate total population in the county. Because of asymmetrical travel between counties, we cannot generally assume that the population of cars in a county is equal to the number registered there. For passenger cars, registrations provide a starting point for estimating populations, but they need to be adjusted by modeling population shifts between counties.

Vehicle population shifts between counties occur on several spatial and temporal scales. An important one is the weekday work commute, when cars drive to neighboring counties, park and drive there during work hours, and come back to their county of registration at night. Vehicle population shifts during the course of a day can also result from travel for shopping, entertainment, and recreation. These latter shifts could occur on both weekdays and weekends, and during the daytime or evening. Vehicle population shifts on a multi-day scale can result from driving to vacation destinations, such as beaches, ski resorts, and amusement parks. Seasonal population shifts can also occur, for example, when people from the east or mid-west drive to Florida, stay for the winter, and return in the spring. Long-haul truck populations and some motor-home populations may have no real home county where they spend most of their time, so registrations provide little basis for estimating their county populations. However, even for these vehicles, registrations will approximate population if the area is large enough, and populations could then be allocated to counties by surrogates developed from U.S. Census and/or U.S. Department of Transportation (USDOT) data.

For metropolitan areas, travel has been modeled using travel demand models of various kinds, which require detailed zone and link information. For the MOVES national county-level default implementation, we need methods that will work for the whole U.S, using data readily available for all of the country's more than 3000 counties. In the next section, as a first step, we describe a method for estimating populations of parked passenger cars that accounts for the population shifts due to travel to and from work.

6. EXAMPLE CALCULATION OF THE NUMBER OF PARKED PASSENGER CARS

This section presents an example of calculating parked passenger car populations for Wayne County, Michigan, that accounts for population shifts due to travel to and from work. The vehicle population of Wayne County increases during the day because more people travel there to work than leave the county to work elsewhere. The method we use relies on data that is available for all U.S. counties, and therefore could be readily implemented for the national default county-level implementation of MOVES. The data required are 1) annual county VMT, 2) county vehicle registrations, 3) inter-county vehicle flow due to commuter travel, and 4) temporal allocations of VMT. We first discuss the sources for these data and then present the example.

Data Sources Available for All Counties

County VMT may be derived from data provided by the Highway Performance Management System (HPMS). These data are available from the Federal Highway Administration (FHWA) and provide roadway lengths and average annual daily travel (AADT) by six urban and six rural roadway

types and six vehicle types. The HPMS data are documented in the *HPMS Field Manual*.⁶ The use of these and other publicly available data to produce county VMT by the twelve roadway types and for appropriate vehicle types (those required by emission models) is discussed in detail in the documentation for EPA's Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Rulemaking (Heavy-Duty Rule)⁷ and in the documentation for EPA's National Emission Inventory (NEI).⁸

Vehicles are registered by all States. FHWA compiles these at the State level. Highly detailed information on county registrations is available commercially, for example, from the Polk Company,⁹ which compiles these data principally for the primary automotive market and the aftermarket parts suppliers. Various surrogates from the U.S. Census and USDOT could also be used to allocate State-level registration data to the counties.

Inter-county vehicle flow due to commuter travel is available in the U.S. Census' *Census Transportation Planning Package* (CTPP),¹⁰ These data include counties of origin and destination for working commutes, as well as time of departure, mode of transportation, and number of persons in a carpool. From these data we can derive the number of vehicles leaving and entering each county in the U.S. for the daily commute.

Hour of day, day of week, and monthly patterns of vehicle operation are available as national and regional averages for urban and rural areas from a USDOT report.¹¹ We are exploring additional sources for region- and county-specific information.

Wayne County Populations of Parked Passenger Cars

Table 1 shows the human population, number of registered passenger cars, daily net commuter vehicle influx, and annual VMT in Wayne County, Michigan, which includes the city of Detroit. Human population is from the 2000 U.S. Census. We obtained Michigan registrations from Table MV1 of *Highway Statistics 2000*¹² and allocated these to Wayne County based on county populations from the U.S. Census. The daily influx of vehicles was derived from 1990 U.S. Census CTPP data.¹³ These data will be, but are not yet, available for 2000. For annual VMT for Light-Duty Gasoline Vehicles (roughly equivalent to passenger cars) for Wayne County for each of twelve roadway types, we started with 2007 estimates prepared for EPA's Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Rulemaking,¹⁴ and adjusted it to 2000 by using the ratio of Michigan VMT for the twelve roadway types from Table VM2 of *Highway Statistics 2000*¹⁵ to the corresponding VMT from the Heavy-Duty Rulemaking.

Table 1. People, cars, VMT, and vehicle population shifts for Wayne County.

Human population (2000)	2,061,162
Passenger cars registered (2000)	1,041,821
Daily net commuter vehicle influx (1990)	75,177
Annual VMT for passenger cars (million miles, 2000)	8,697

To determine the population of operating passenger cars, the VMT for light-duty gasoline vehicles (LDGV) on each roadway type was divided by 365 to produce an average daily VMT. This daily VMT was allocated to each hour of the day using the "Weekday Urban Traffic Pattern" for 1992 produced from an analysis of nationwide automatic traffic recorder data.¹⁶ Using Equation 14, the population of vehicles operating on each roadway type was calculated by dividing the hourly VMT by the average speed of LDGVs on each roadway type from the Heavy-Duty Rule Procedures Document.¹⁷

Figure 2. Population of vehicles operating in Wayne county on a weekday.

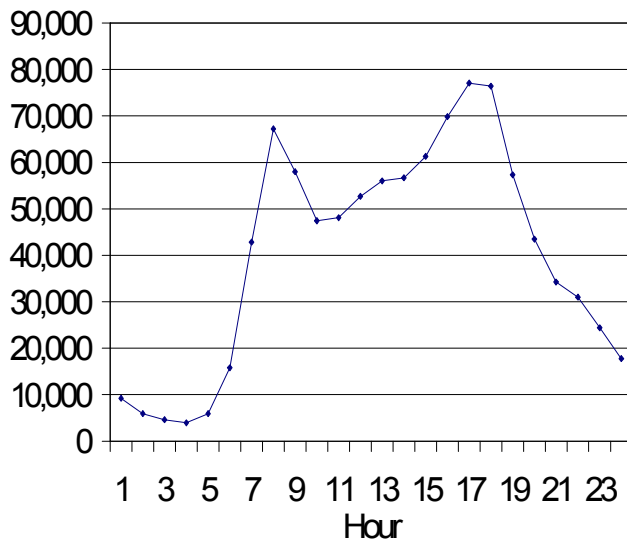


Figure 2 shows the hourly population of operating passenger cars, which exhibits the morning and afternoon peaks typical of the weekday urban commute.

We approximated the daily net influx of commuter vehicles as occurring linearly during the three-hour period between 5 am and 8 am, and the efflux as occurring linearly between 4 pm and 7 pm. Vehicles parked in the county are then calculated as total vehicle population (registrations plus net influx) minus operating vehicles. Figure 3 shows the parked vehicles thus calculated in Wayne County. The parked pattern is approximately the reverse of the operating pattern—as more vehicles operate, fewer are parked—but modified by the influx of vehicles. Although we demonstrate this method with a single county, the data to perform these calculations are available nationally and could be included in the MOVES county-level default database, so this calculation could be performed for all U.S. counties. A consistency check on such a database would be that, nationally, the total net influxes should equal the total net effluxes summed across all counties.

Figure 3. Population of parked passenger cars in Wayne County on a weekday.

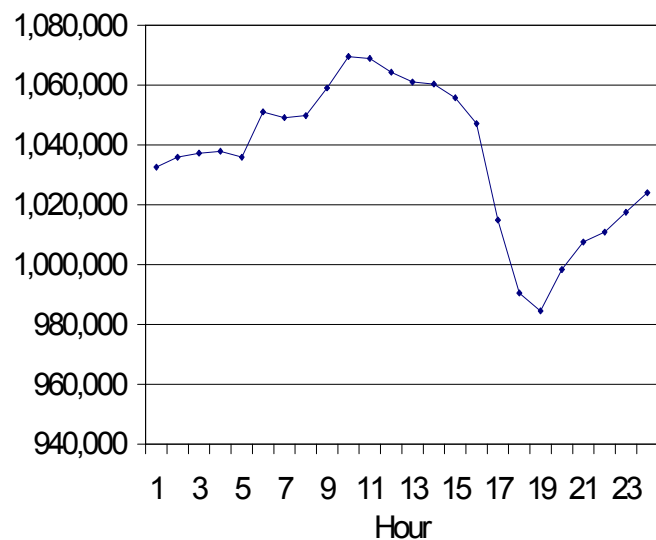


Figure 4. Operating, parked, and total passenger car populations in Wayne County on a weekday.

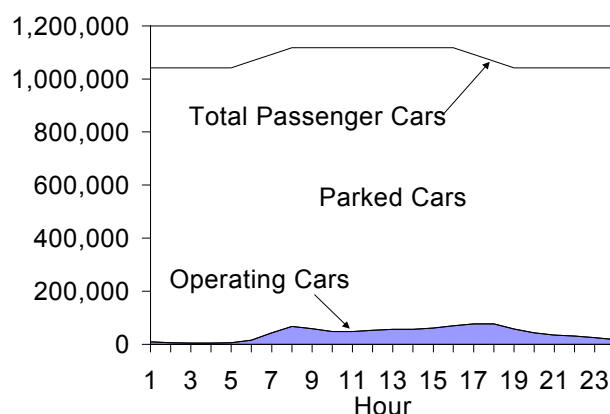


Figure 4 shows both parked and operating vehicles in Wayne County. This figure shows that most passenger cars are parked most of the time, and that the operating activity and population fluxes have a relatively small effect on the total population of parked vehicles. The population of operating vehicles varies nearly twenty fold over the course of the day, but the population of parked vehicles varies by only about ten percent.

7. CONCLUSIONS AND DISCUSSION

In order to model mobile source emissions in an environment of changing driving patterns, activity cannot simply be modeled as a function of VMT based on static relationships of MAR, daily trips, speed and commute

patterns. As these and other variables are manipulated to reflect specific current driving regimes and to model future regimes and policy initiatives, it is necessary that the relationships between these variables remain consistent. If VMT is assumed to change, we must determine the correct and consistent combination of changes in vehicle population and trip parameters. Non-traveling emissions need to be de-linked from VMT. These ideas need to be implemented on all scales of analysis, from nation to intersection.

Hydrocarbon emissions from parked vehicles are about 20 percent of HC emissions from the total on-road fleet. Populations of parked, operating, and extended idling vehicles must meet the basic constraint that they sum to the total vehicle population. Hourly parked populations of passenger cars can be determined as the difference between hourly total and hourly operating populations. Hourly populations of operating passenger cars can be calculated from VMT and average speed. Total hourly populations of passenger cars can be determined from registrations and net inter-county vehicle flows obtained from U.S. Census data. We applied these ideas to Wayne County, Michigan, but they could be readily applied to all U.S. counties. However, our example only accounts for shifts in passenger car populations due to travel to and from work. Methods are needed to model inter-county population flows of other vehicle types and resulting from other types of travel.

Similar ideas apply to non-road emissions. Parked (off), operating, and extended idling populations should sum to total population. The non-road analogue to “trips” would be “on-off cycles”, and a similar set of relationships between off times, cycle times, and starts would apply. The distribution of on-off cycles would affect the distribution of off times. The application of these ideas to non-road vehicles and equipment poses greater challenges, because government agencies do not register and gather activity information on most of them to anywhere near the level that is routinely done for on-road vehicles.

8. DISCLAIMER

This paper does not necessarily represent official EPA policy, nor is it a formal part of the MOVES Design. The primary purpose in presenting this paper is to facilitate the exchange of technical information and to inform the scientific community of ongoing work within EPA. Parts of this work may or may not be incorporated into the MOVES model. Mention of commercial products does not constitute an endorsement by EPA.

9. REFERENCES

1. Koupal, J.; Cumberworth, M.; Michaels, H.; Beardsley, M.; Brzezinski, D. *Draft Design and Implementation Plan for EPA's Multi-Scale Motor Vehicle and Equipment Emission System (MOVES)*, U.S. Environmental Protection Agency, Ann Arbor, MI, October 2002; EPA420-P-02-006. <http://www.epa.gov/otaq/models/ngm/p02006.pdf>.
2. Koupal, J.; Hart, C.; Brzezinski, D.; Giannelli, R.; Bailey, C. *Draft Emission Analysis Plan for MOVES GHG*, U.S. Environmental Protection Agency, Ann Arbor, MI, November 2002; EPA420-P-02-008.
3. The MOBILE6 model and full documentation are available from <http://www.epa.gov/otaq/m6.htm>.
4. U.S. Department of Transportation. *2001 National Household Travel Survey (NHTS)*. http://nhts.ornl.gov/2001/html_files/introduction.shtml.

5. U.S. Census Bureau. *1997 Vehicle Inventory and Use Survey (VIUS)*.
<http://www.census.gov/svsd/www/97vehinv.html>.
2002 Vehicle Inventory and Use Survey (VIUS). <http://www.census.gov/mp/www/rom/msrom7i.html>.
6. U.S. Department of Transportation, Federal Highway Administration. *Highway Performance Monitoring System Field Manual*. December 2000.
<http://www.fhwa.dot.gov/ohim/hpmsmanl/hpms.htm>
7. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for The Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking*. October 2000, EPA420-R-00-020. <http://www.epa.gov/otaq/hdmodels.htm>.
8. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *Procedures Document for National Emission Inventory, Criteria Air Pollutants 1985-1999*, March 2001, Research Triangle Park, NC 27711. EPA-454/R-01-006. <http://www.epa.gov/ttn/chief/trends>.
9. R. L. Polk & Co., 26955 Northwestern Hwy, Southfield, MI 48034. www.polk.com.
10. U.S. Department of Transportation. *Census Transportation Planning Package 2000*,
<http://www.fhwa.dot.gov/ctpp>.
11. Festin, S.M. *Summary of National and Regional Travel Trends: 1970-1995*, May 1996, Office of Highway Information Management, United States Department of Transportation, Federal Highway Administration, Washington, D.C. <http://www.fhwa.dot.gov/ohim/bluebook.pdf>.
12. U.S. Department of Transportation, Federal Highway Administration "State Motor-Vehicle Registrations - 2000," Table MV-1 in *Highway Statistics 2000*. October 2001.
<http://www.fhwa.dot.gov/ohim/hs00/mv.htm>.
13. TranStats web page of the Bureau of Transportation Statistics: <http://www.itdb.bts.gov/>, then select "Passenger Travel" from the Data Library.
14. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for The Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking*. October 2000, EPA420-R-00-020. <http://www.epa.gov/otaq/hdmodels.htm>.
15. U.S. Department of Transportation, Federal Highway Administration "Functional System Travel - 2000, Annual Vehicle Miles," Table VM-2 in *Highway Statistics 2000*. October 2002.
<http://www.fhwa.dot.gov/ohim/hs00/re.htm>.
16. Festin, S.M. *Summary of National and Regional Travel Trends: 1970-1995*, May 1996, Office of Highway Information Management, United States Department of Transportation, Federal Highway Administration, Washington, D.C. <http://www.fhwa.dot.gov/ohim/bluebook.pdf>.
17. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Table VI-3, "Average Speeds by Road Type and Vehicle Type" from *Procedures for Developing Base Year and Future Year Mass and Modeling Inventories for The Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel (HDD) Rulemaking*. October 2000, EPA420-R-00-020
<http://www.epa.gov/otaq/hdmodels.htm>.